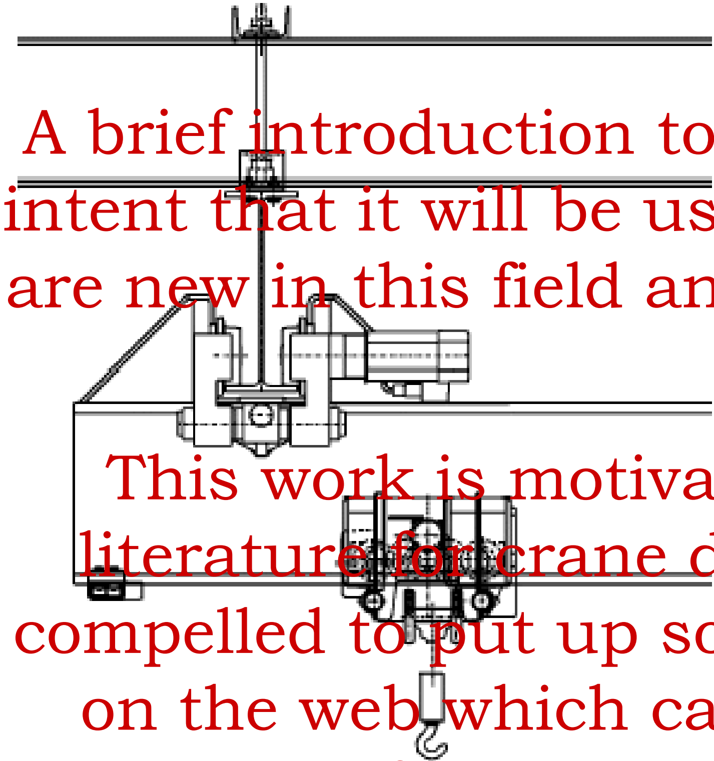
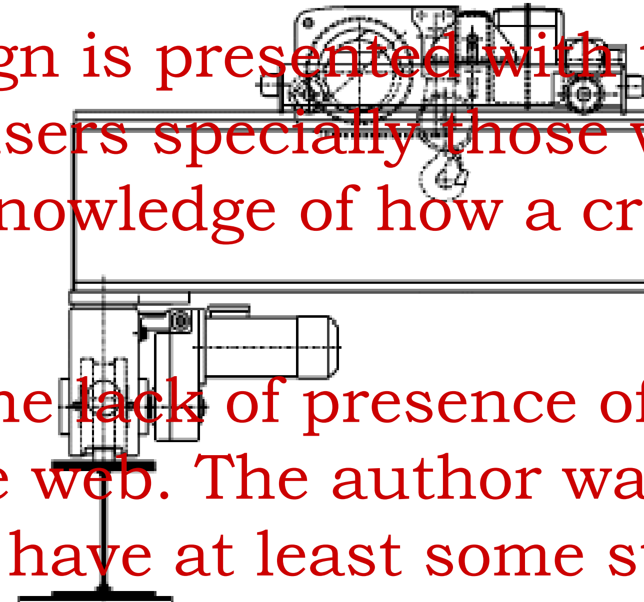
Crane Design Basics





A brief introduction to Crane Design is presented with the intent that it will be useful to the users specially those who are new in this field and have no knowledge of how a crane is built.

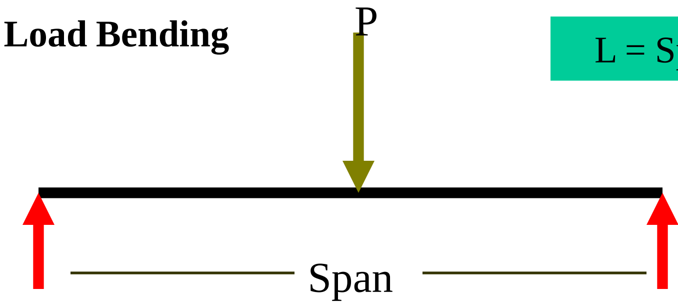
This work is motivated due to the lack of presence of literature for crane design on the web. The author was compelled to put up some effort to have at least some stuff on the web which can at least give a introductory level information to engineers and students.

Feel free to send me a mail with questions or comments

Beam Calculatorcrane_calc.xls

Dead Load Bending

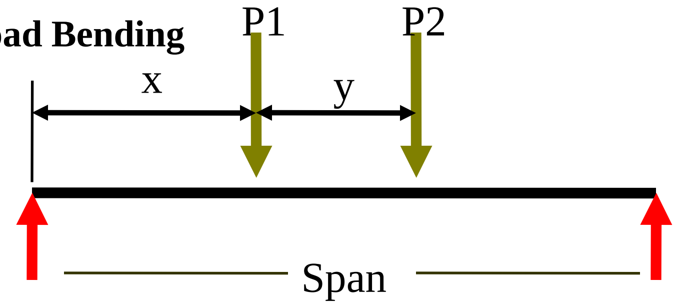
L = Span



$$\text{Max Moment} = \frac{\omega l^2}{8} + \frac{Pl}{4}$$

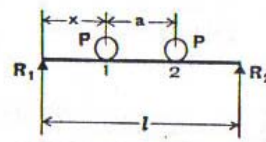
P = Center drive + Controls
w = Footwalk + Beam + Lineshaft
Dynamic Mx = Max Moment x factor
Dynamic My = Max Moment x factor

Live Load Bending



41. SIMPLE BEAM—TWO EQUAL CONCENTRATED MOVING LOADS

$ECL = \frac{2P(L - \frac{1}{2} W.B)^2}{L^2}$

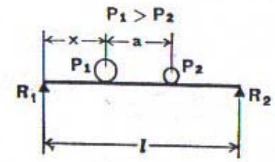


R_1 max. = V_1 max. (at x = o) . . . . $= P\left(2 - \frac{a}{l}\right)$

M max.:

- when $a < (2 - \sqrt{2})\, l = .586 l$, under load 1 at $x = \frac{1}{2}\left(l - \frac{a}{2}\right)$ $= \frac{P}{2l}\left(l - \frac{a}{2}\right)^2$
- when $a > (2 - \sqrt{2})\, l = .586 l$, with one load at center of span (case 40) $= \frac{Pl}{4}$

42. SIMPLE BEAM—TWO UNEQUAL CONCENTRATED MOVING LOADS



R_1 max. = V_1 max. (at x = o) . . . . $= P_1 + P_2 \frac{l - a}{l}$

M max.:

- under P_1, at $x = \frac{1}{2}\left(l - \frac{P_2 a}{P_1 + P_2}\right)$ $= (P_1 + P_2)\frac{x^2}{l}$
- M max. may occur with larger load at center of span and other load off span (case 40) $= \frac{P_1 l}{4}$

If P1=P2, use the Case 41, otherwise use Case 42. Also calculate the Max moment using the formula PL/4. In other words, to be conservative, use the largest value obtained.

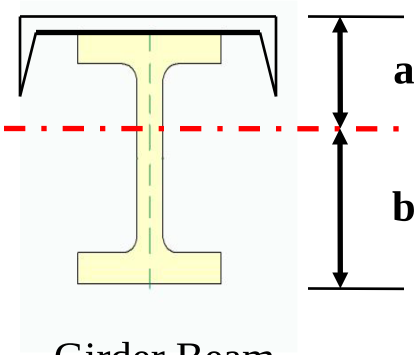
Dynamic Mx = LL Mx + DL Mx
My = LL My + DL My

$$f_{b_{xT}} = \frac{M_x}{S_{bott}} \leq 0.6F_y$$

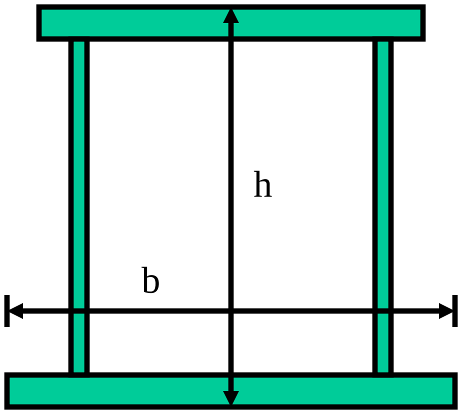
$$f_{b_{xC}} = \frac{M_x}{S_{Top}}$$

$$f_{b_{yC}} = \frac{M_y}{S_{Top}}$$

$$\frac{f_{b_{xC}}}{F_{b_x}} + \frac{f_{b_{yC}}}{0.6F_y} \leq 1.0$$



Girder Beam
Available to 60 ft max. length



Fabricated/Box Beam

L/h should not exceed 25
L/b should not exceed 65

DL – Dead load, LL = Live Load, Fy = Yield normally @ 36 ksi for A36 material, Fb = Allowable Stress

$$\Delta = \frac{5wl^4}{384EI}$$ **For Uniform Load**

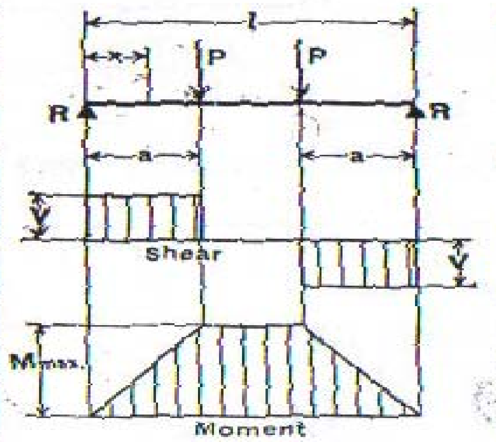
$$\Delta = \frac{Pl^3}{48EI}$$ **For Conc. Load**

For Trolley:

$$P = \frac{LL + TW}{2}$$

$$\Delta = \frac{Pa}{24EI}\left[3l^2 - 4a^2\right]$$

9. SIMPLE BEAM—TWO EQUAL CONCENTRATED LOADS SYMMETRICALLY PLACED



Total Equiv. Uniform Load . . . . . . $= \frac{8Pa}{l}$

R = V . . . . $= P$

M max. (between loads) . . . . . . $= Pa$

Mx (when x < a) . . . . . $= Px$

Δmax. (at center) . . . . $= \frac{Pa}{24EI}(3l^2 - 4a^2)$

Δx (when x < a) . . . . $= \frac{Px}{6EI}(3la - 3a^2 - x^2)$

Δx (when x ≥ a and < (l − a)) . . . $= \frac{Pa}{6EI}(3lx - 3x^2 - a^2)$

3.5.5 Deflection and Camber

3.5.5.1 The maximum vertical deflection of uncambered girders produced by the dead load, the weight of hoist, trolley and the rated load shall not exceed 1/600 of the span. Vertical inertia forces shall not be considered in determining deflection.

1/600

3.5.5.2 The maximum vertical deflection of cambered girders produced by the weight of the hoist, trolley and the rated load shall not exceed 1/888 of the span. Vertical inertia forces shall not be considered in determining deflection.

1/888

3.5.5.3 Box girders and single web girders should be cambered an amount equal to the dead load deflection plus one-half of the live load deflection.

3.5.6 Single Web Girders

Single web girders include wide flange beams, standard I beams, beams reinforced with plates, or other structural configurations having a single web. Where necessary, an auxiliary girder or other suitable means should be provided to support overhanging loads to prevent undue torsional and lateral deflections.

The maximum stresses with combined loading for Case 1 shall not exceed:

Tension (ksi) = $0.6\,\sigma_{yp}$ $= 0.6\sigma_y$

Compression (ksi) = $\dfrac{12{,}000}{\frac{Ld}{A_f}}$ with maximum of $0.6\,\sigma_{yp}$ $= \dfrac{12000}{L\dfrac{d}{A_f}}$

Use when the flanges are not welded on the top and bottom

where: L = span (unbraced length of top flange) (inches)
A_f = area of compression flange (in²)
d = depth of beam (inches)

Shear = $0.35\,\sigma_{yp}$

$$L/r_t \geq \sqrt{102000/F_y} \text{ And } L/r_t \leq \sqrt{510000/F_y}, F_{b2} = \left[\frac{2}{3} - \frac{F_y\left(L/r_t\right)^2}{1530000}\right]F_y$$

$$Otherwise, F_{b_3} = \frac{170000}{\left(L/r_t\right)^2}$$

$$F_{b_1} = \frac{12000}{L\left(d/A_f\right)}(perCMAA)$$

$$F_b = 0.6\sigma_y$$

Select Allowable Stress which is the Greatest of all. Then check for the following:

$$\sigma_{Tensile} < 0.6\sigma_y$$

$$\frac{\sigma_{comp\,x}}{f_b} + \frac{\sigma_{comp\,y}}{0.6\sigma_y} < 1$$

3.3.2.4.2 Due to Vertical Loads:

Torsional moment due to vertical forces acting eccentric to the vertical neutral axis of the girder shall be considered as those vertical forces multiplied by the horizontal distance between the centerline of the forces and the shear center of the girder.

3.3.2.4.3 Due to Lateral Loads:

The torsional moment due to the lateral forces acting eccentric to the horizontal neutral axis of the girder shall be considered as those horizontal forces multiplied by the vertical distance between the centerline of the forces and the shear center of the girder.

3.3.2.5 Load Combination

The combined stresses shall be calculated for the following design cases:

3.3.2.5.1 Case 1: Crane in regular use under principal loading (Stress Level 1)

$DL\ (DLF_B) + TL\ (DLF_T) + LL\ (1 + HLF) + IFD$

3.3.2.5.2 Case 2: Crane in regular use under principal and additional loading (Stress Level 2)

$DL\ (DLF_B) + TL\ (DLF_T) + LL\ (1 + HLF) + IFD + WLO + SK$

3.3.2.5.3 Case 3: Extraordinary Loads (Stress Level 3)

3.3.2.5.3.1 Crane subjected to out of service wind

$DL + TL + WLS$

3.3.2.5.3.2 Crane in collision

$DL + TL + LL + CF$

3.3.2.5.3.3 Test Loads

CMAA recommends test load not exceed 125 percent of rated load.

This is a empirical formula

3.3.2.6 Local Bending of Flanges Due to Wheel Loads

3.3.2.6.1 Each wheel load shall be considered as a concentrated load applied at the center of wheel contact with the flange (Figure 3.3.2.6-1). Local flange bending stresses in the lateral (x) and longitudinal (y) direction at certain critical points may be calculated from the following formulas:

Underside of flange at flange-to-web transition —Point 0:

$$\sigma_{x0} = C_{x0} \frac{P}{(t_a)^2} \qquad \sigma_{Y0} = C_{Y0} \frac{P}{(t_a)^2}$$

Underside of flange directly beneath wheel contact point —Point 1:

$$\sigma_{x1} = C_{x1} \frac{P}{(t_a)^2} \qquad \sigma_{Y1} = C_{Y1} \frac{P}{(t_a)^2}$$

For a crane where the trolley is running on the bottom flange, it is necessary to check the local bending of flange due to the wheel load. The flange must be OK before a beam selection is made.

Topside of flange at flange-to-web transition —Point 2:

$\sigma_{x2} = -\sigma_{x0}$ $\sigma_{Y2} = -\sigma_{Y0}$

For tapered flange sections (Figure 3.3.2.6-2)

$$C_{x0} = -1.096 + 1.095\lambda + 0.192e^{-6.0\lambda}$$
$$C_{x1} = 3.965 - 4.835\lambda - 3.965e^{-2.675\lambda}$$
$$C_{Y0} = -0.981 - 1.479\lambda + 1.120e^{1.322\lambda}$$
$$C_{Y1} = 1.810 - 1.150\lambda + 1.060e^{-7.70\lambda}$$
$$t_a = t_f - \left[\frac{b}{24}\right] + \left[\frac{a}{6}\right]$$ for standard "S" section

where: t_f = published flange thickness for standard "S" section (inches)

For parallel flange section (Figure 3.3.2.6-3 & 4)

$$C_{x0} = -2.110 + 1.977\lambda + 0.0076e^{6.53\lambda}$$
$$C_{x1} = 10.108 - 7.408\lambda - 10.108e^{-1.364\lambda}$$
$$C_{Y0} = 0.050 - 0.580\lambda + 0.148e^{3.015\lambda}$$
$$C_{Y1} = 2.230 - 1.49\lambda + 1.390e^{-18.33\lambda}$$

For single web symmetrical sections (Figure 3.3.2.6-2 & 3)

$$\lambda = \frac{2a}{b - t_w}$$

b = section width across flanges (inches)

For other cases (Figure 3.3.2.6-4)

$$\lambda = \frac{a}{b' - \frac{t_w}{2}}$$

b' = distance from centerline of web to edge of flange (inches)

where:
- P = Load per wheel including HLF (pounds)
- t_a = Flange thickness at point of load application (inches)
- t_w = Web thickness (inches)
- a = Distance from edge of flange to point of wheel load application (inches) (Center of wheel contact)
- e = Napierian base = 2.71828...

3.3.2.6.2 The localized stresses due to local bending effects imposed by wheel loads calculated at points 0 and 1 are to be combined with the stresses due to the Case 2 loading specified in paragraph 3.3.2.5.2 of this Specification.

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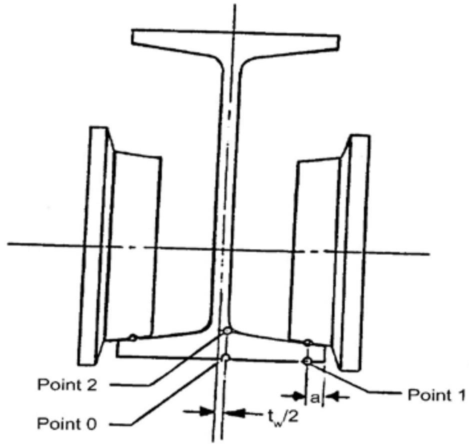


Figure 3.3.2.6-1

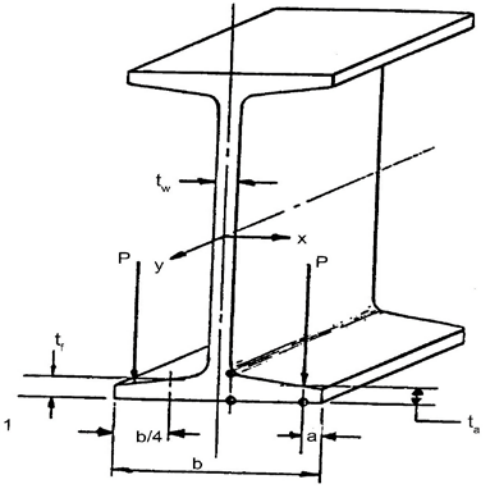


Figure 3.3.2.6-2

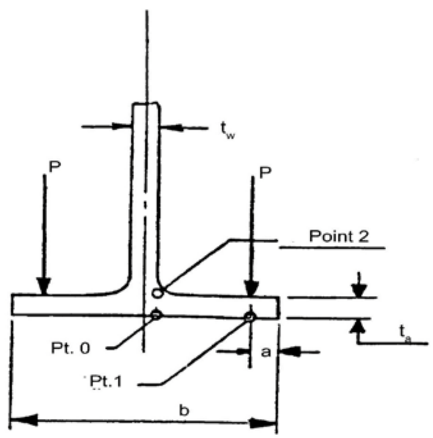
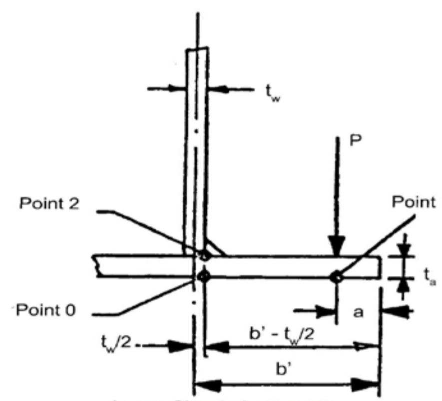


Figure 3.3.2.6-3



Lower Chord of a Box Girder
Figure 3.3.2.6-4

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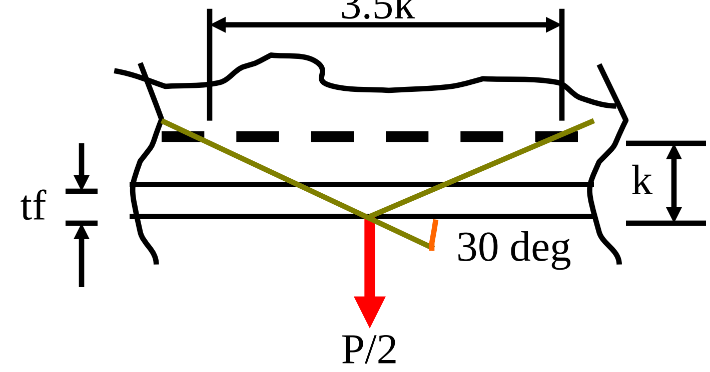
The lower flange of the crane beam must be checked for:

1) Tension in the web. 2) Bending of the bottom flange.

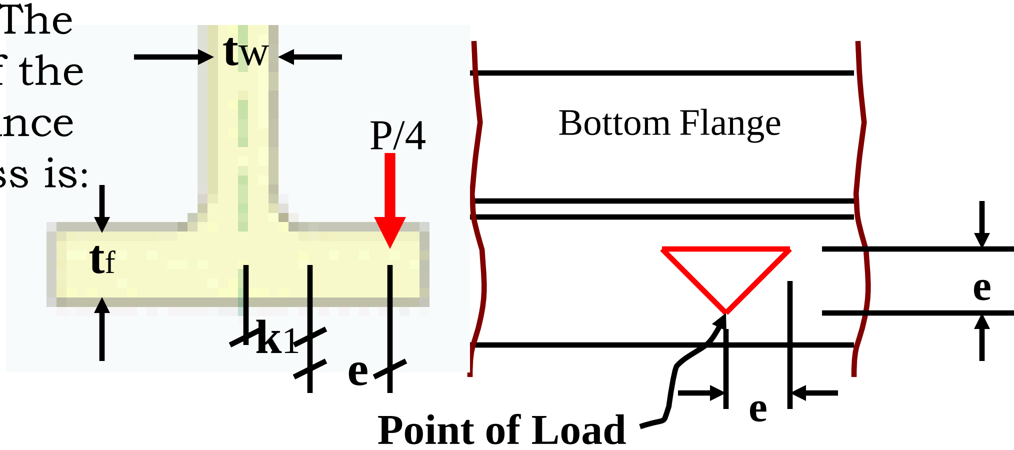
Refer to the figure, the length of resistance is seen to be 3.5k. The 30 degree angle is a consensus figure used for many years. Assuming 4 wheels (2 pair) at each end of the crane, each wheel will support P/4 delivered to the supporting crane beam. Two wheels cause the web tension, so the load is P/2. Tensile stress in the web is:

$$f_t = \frac{P}{2A} = \frac{P}{2t_w(3.5)} = \frac{P}{7t_w}$$



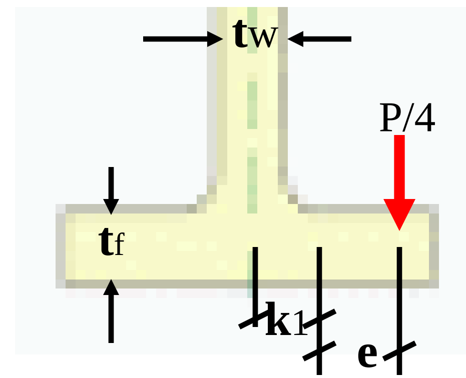
Flange bending depends upon the location of the wheels with respect to the beam web. This dimension is 'e' as shown in the figure. The wheel load is P/4. Longitudinal length of the flange participating in the bending resistance is 2e per yield line analysis. Bending stress is:

$$f_b = \frac{M}{S} = \frac{Pe}{4}\frac{6}{bd^2} = \frac{Pe}{4}\frac{6}{2et_f^2} = \frac{0.75P}{t_f^2}$$



Refer to Engineering Journal, 4th quarter, 1982, Tips for avoiding Crane Runway Problems by David T. Ricker

Now, the angle is changed from 30 degree to 45 degrees.



Capacity = 6000 lb

Hoist wt = 1000 lb

Load = 6000 +1000 = 7000

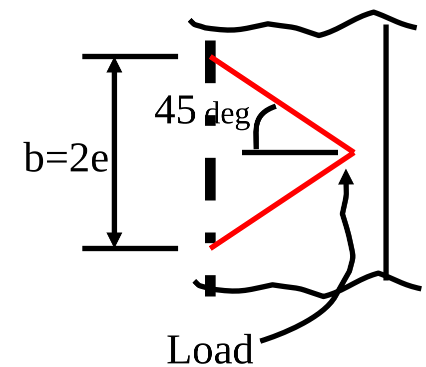
Wheel load = 7000/4 = 1750

With 15% impact = 1750(1.15) = 2013 lb

b =11.5, e = b/2 = 5.75

Tf = 0.875

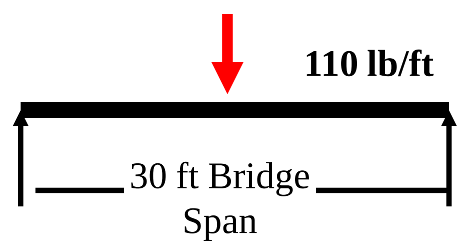
M = 2013(5.75) = 11574.75



Stress = M/S = 11574.75 • (6)/(11.5)(0.875)^2 = 7890.15

Moment = 7000(1.15)(30)(12)/4 + 110((12)(30))^2/(8(12)) = 873000 lb-in
Stress= 873000/280 = 3117.8

$$\sigma = \sqrt{\sigma_x^2 + \sigma_y^2 + \sigma_x \sigma_y} = \sqrt{3117.8^2 + 7890.15^2 + 3117.8(7890.15)}$$



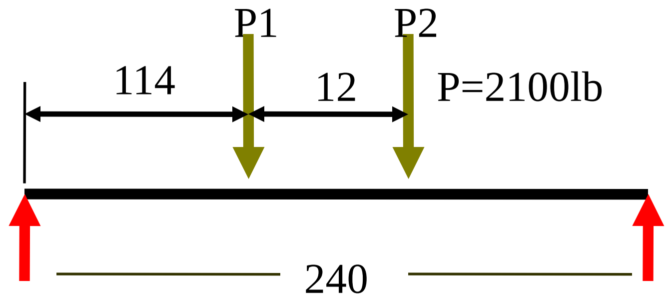
Stress = 9827 << 0.6 Sigma y (21600) **OK**

EXAMPLE – Simple Approach

Capacity: 2 Ton (4000 Lb), Span: 20 Ft (480 in)

Hoist Wt: 200 Lb, Hoist W.B: 12 in

Vertical Impact factor = 15%, Hor. Impact = 10%



Solution:

Beam must be checked for Lower flange load, if the trolley is under running

$$Mx = \frac{wL^2}{8} + \frac{P}{2L}\left(L - \frac{a}{2}\right)^2$$

$$Mx = \frac{31.8}{12} \times \frac{240^2}{8} + \frac{2100 \times 1.15}{2 \times 240}\left(240 - \frac{12}{2}\right)^2 = 294571.1$$

$$\sigma_x = \frac{M_x}{S_x} = \frac{294571.1}{36.4} = 8092.6$$

$$\sigma_x = \frac{M_y}{S_y} = \frac{294571.1 \times 1.1 \times 0.1}{9.27 \times 1.15} = 3039.5$$

$$\delta = \frac{5wL^4}{384EI} + Pa\frac{(3L^2 - 4a^2)}{24EI}$$

$$\delta = \frac{5(31.8)240^4}{384 \times 12 \times 218E} + 2100 \times 1.15 \times 114\frac{(3 \times 240^2 - 4 \times 114^2)}{24 \times 218E}$$

$$\delta = 0.237 < \frac{L}{600} = 0.4$$

OK

Say, for example, we select a A36, S beam S12x31.8#, Ix=218, Iy=37.1, Sx=36.4, Sy=9.27, d/Af=4.41

P=2100 lb, w = 31.8/12 lb/in

$$\sigma_{comb} = 8092.6 + 3039.5 = 11132.1$$

$$\sigma_{all1} = 0.6\sigma_y = 0.6 \times 36 = 216000$$

$$\sigma_{all2} = \frac{12000}{L \times d/A_f} = \frac{12000}{240 \times 4.41} = 11337.8$$

$$\sigma_{all} = Min\_of - \sigma_{all1}, \sigma_{all2} = 11337.8$$

$$\sigma_{comb} < \sigma_{all.}$$

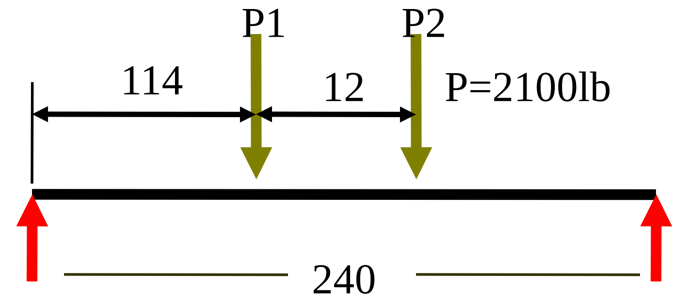
OK

DLF = $1.1 \le 1.05 + \frac{Br.speed}{2000} \le 1.2$ = 1.10

HLF = $0.15 \le 0.005(HoistSpeed) \le 0.5$ = 1.15

IFD = $0.078(Bridge\_acc.) \le 0.025$ = 0.39

Wheel Ld (P1/P2) = $\frac{C}{2}\left[\frac{T\_WB - X_1 - X_2}{T\_WB}\right](HLF) + \left[\frac{T\_Wt}{2}\right](DLF)$ = 2410



Moment A = HLF x M (whichever is greater) = $P_1 > P_2, M = \frac{(P_1+P_2)}{L}X^2, X = 0.5\left[\frac{L - WB \times P_2}{P_1 + P_2}\right], OR, M = \frac{PL}{4}$ = 166290

Moment B = IFD x M (whichever is greater) = 56394

Static Moment = $\frac{wL^2}{8} + \cancel{\frac{PL}{4}}$ = 19080

Beam must be checked for Lower flange load, if the trolley is under running

$$d1 = \frac{5wL^4}{384EI} = 0.0181$$

Moment C = DLF x Static Moment = 20988

$$d2 = \cancel{\frac{PL^3}{3EI}} = 0$$

Moment D = IFD x Static Moment = 7441.2

Moment Mx = A+C = 187278

Moment My = B+D = 63835.2

$$d3 = \frac{(P_1 + P_2)}{2} a \frac{[3L^2 - 4a^2]}{24EI} = 0.2188$$

Tensile Stress = $\sigma = Mx/Sx$ = 5.15 < 0.6(36) **OK**

$$d4 = \frac{P_1 L^3}{48EI} = 0.1098$$

Comp. Stress X = $\sigma = Mx/Sx$ = 5.15

Comp. Stress Y = $\sigma = My/Sy$ = 17.07

Total Deflection = d1+d2+(Greater of d3 and d4)

Deflection = 0.0181+0+0.2188 = 0.2369 in

$\frac{C_x}{f_b} + \frac{C_y}{0.6F_y} < 1 = \frac{5.15}{21.6} + \frac{17.07}{21.6} = 1.03 > 1$ **ERR**

Deflection 0.2369 < L/600 (0.4) **OK**

Above calculation is for S12x31.8 Beam